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A STUDY OF MAGNESIA CEMENT AND THE FACTORS AFFECTING ITS PHYSICAL PROPERTIES

by

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A Thesis Submitted for the Degree
BACHELOR OF SCIENCE
Chemical Engineering Course

UNIVERSITY OF WISCONSIN
1916

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PART ONE

GENERAL DISCUSSION OF MAGNESIA CEMENT.

Magnesia Cement and its Uses.

In 1853 Sorel, in France, discovered that when finely ground MgO is mixed with a solution of magnesium chloride and allowed to stand, it sets into a hard dense mass. The cement, so made and usually called " Sorel Cement," is of great tensile strength, very quick setting, and can be used with almost any solid material as an aggregate. Today the cement is used chiefly for composition floors.

The powdered MgO, known as calcined magnesite, or magnesite cement, is obtained by the calcination of natural magnesite ($MgCO_3$). Magnesite occurs in Greece, California, Canada, Selisia, Steinmark, and South Africa. The principal deposits are in Greece, California, and Canada. Before the war the California beds were unable to compete with the Grecian on account of the high labor and transportation costs.

The MgO is obtained by burning the carbonate in kilns, and then grinding it. The temperature of calcination of the magnesite depends on the use to which the MgO is to be put. For use as a cement it should be calcined at from 700 to 900 degrees Centigrade. The kilns are vertical brick shafts, lined with fire brick. The magnesite is fed in at the top, and passes down the shaft, being heated by the rising products of the combustion of gas, oil, or coal. The calcined material is taken out at the bottom of the shaft. About 24 hours are allowed for the material to pass thru the kilns, of which two hours are spent in the hottest zone, where most of the carbon dioxide is driven off. The loss in

weight is the CO_2 driven off, plus a very small amount of moisture. Theoretically, then, the loss should be 50 per cent. In actual practice however, it usually takes two and one third tons of magnesite to make one ton of calcined magnesite. The loss is due to the under-calcination of some of the carbonate.

The grinding is usually done between a pair of millstones. Tube mills have been tried for grinding, but they have not proved as satisfactory as millstones.

The calcined magnesite consists of from 70 to 90 per cent. of MgO, with CaO, SiO_2, Iron and Aluminum oxides, and Sulphur as the chief impurities. It has a specific gravity of about 3.07.

One of the greatest difficulties met with by the users of magnesite cement lies in the securing of a uniform product. If the cement has been calcined at too high a temperature some of the MgO will become inactive, refusing to react with the $MgCl_2$. In this form it is known as "dead burnt" MgO. This dead burnt MgO, of course, weakens the cement, and it present in too large amounts it will make the cement unusable. The chemical analysis of the cement does not show how much of the dead burnt MgO there is, but only gives the total percentage of the MgO in the cement. The only way known of determining the amount of dead burnt MgO is to treat the cement with pure $MgCl_2$, wash out the excess with cold water, and from the amount of $MgCl_2$ which has been found to have combined with the cement, that is, the $MgCl_2$ which was not washed out by the water, calculate the amount of active MgO in the cement.

The $MgCl_2$ which is used as a solution of from 22° to 28° Beaume in strength, is usually obtained from Germany, where it

is made from "Carnallite" ($MgCl_2.KCl.6\ H_2O$). The last liquor from the KCl extraction from the crude Carnallite, at a specific gravity of 1.32, is evaporated to a specific gravity of 1.34, when the chlorides of sodium, and calcium, together with the magnesium sulphate, separate out from the solution. The remaining liquid is run into flasks, and on cooling solidifies, forming a white transluscent mass, which is about fifty per cent, magnesium chloride. Magnesium chloride is also made in America in Michigan and California. The Michigan product is obtained by treating the waste liquors from salt manafacture, which contain a high percentage of $MgCl_2$. The California $MgCl_2$ is also obtained as a by-product of salt manafacturing, either in the form of crystals or as a concentrated solution of $MgCl_2$ known as "bittern"

When Sorel cement was first announced it was thought that a valuable substitute for Portland cement had been found. It was strong; it set quickly; and it could be made up with a wide range of aggregates. When made up with a filler of marble dust, suitably colored, a very good artificial marble was obtained. Patents were taken out and companies in several countries began the manafacture of artificial building stone. But it was soon found that the stone made in this way could not be used for out of door work or where it was subjected to moisture, without absorbing water and disintegrating. It is this property of magnesia cement of absorbing water until it disintegrates that limits it uses. Sorel cement is particularily adapted however for use as flooring, and it is in this field that the widest use is made of it today.

The cement is made up with different aggregates, depending on the type of floor and the method of choice of the manafacturer.

The fillers generaly used are sawdust for resiliency, talc for smoothness, silica for hardness, asbestos fibre as a binder, red slate as a filler, and iron oxide as a coloring material. The floors can be laid on concrete. Some manafacturers prefer to have the concrete roughed, while others claim to be able to lay a floor that will adhere to a smooth surfaced concrete. The floors can also be laid directly on a wood surface. They cannot be laid, it is claimed by one manafacturer , directly on plaster, plaster board, brick, or terra cotta. The first layer of the floor is usually made up with a fibrous material such as sawdust, wood flour, or asbestos fibre. The second layer is finer grained and contains the coloring material. The surface may be finished by trowelling, or by burnishing and scraping after the cement has set. The floors can be kept in good condition by periodically oiling and waxing them. A very good looking resilient floor can be made in this way.

The principal faults of composition floors are: efflourescence, i.e. the appearance of free magnesium chloride on the surface of the floor; expansion and warping; fading; and cracking. The causes for these defects may lie in the raw materials, in the proportions of the constituents used, or in the laying of the floor.

Little is known of the effects on the floor of the different impurities in the calcined magnesite. These impurities, however, with the exception of the dead burned MgO, are usually present in such small amounts that they do not affect the floor materially. As has already been pointed out, dead burnt magnesia is the principal impurity in magnesite cement. The only way it can satisfact-

orily guarded against is by a thorough mixing of the different burnings of the magnesite before grinding. If this is not done there may be a few barrels of the dead burnt stuff in a carload of the cement. Where this dead burnt cement was used it would result in weak spots in the floor. A standardization of the calcining process which would prevent, or at least uniformly distribute, the dead burnt MgO, is one of the first requisites for the production of a uniform cement.

The impurities in the $MgCl_2$ are the chlorides of calcium, sodium, and potassium. They are usually present in such small quantities as to have no effect on the floor.

There is little data available as to the proportions of materials which should be used for floors. Each manafacturer has his own formula, and even he is in doubt as to how this formula should be varied with different magnesite cements. The density and amount of $MgCl_2$ solution used also varies with the manafacturer. The Germans use densities from 26° to 28° Beaume in strength while the American manafacturers use densities from 22° to 23° Beaume in strength. In general, too much $MgCl_2$ causes efflourescence, while an insufficient amount causes expansion and warping.

The defects due to faulty laying of the floor can be overcome by careful supervision and the employment of skilled workmen.

The general desire today of users of composition floors is a standardization of the entire business. First, the raw materials must be standardized, so that the user can know just what he is getting, and can be sure of a uniform material. Then the formulae

of the floors should be worked out so that the architect can specify what proportions of materials etc. should be used to give the floor he desires, and so he can be sure that he will obtain the result specified. As it is now, the architect can only specify that a composition floor shall be used, and must trust to the skill and reliability of the manafacturer of the floor for a satisfactory result.

CHEMICAL RESEARCH ON MAGNESIA CEMENT.

Sorel[1], though he discovered magnesia cement, did no work on its composition. He merely announced it to be a magnesia oxychloride cement, saying that the hardness varied with the strength of the $MgCl_2$ solutiom used, and that solutions ranging in densities from 20° to 30° Beaume were the most suitable.

Bender[2] in 1870 was the first to publish anything on the chemical composition of magnesia cement. He made tests on six months old specimens of magnesia cement, which had been stored in air. In making his determinations, he considered that the CO_2 which had been absorbed from the air had united with the MgO to form the normal anhydrous carbonate, the rest of the MgO was considered as being free to react with the $MgCl_2$. He extracted the excess $MgCl_2$ with cold water, assumed the unextracted $MgCl_2$ to be combined with the free MgO, and computed his composition formulae for the cement. For the six months, air stored Sorel cement he found it to be $MgCl_2.5MgO.17H_2O$. When this was treated with water and dried over SO_3 it lost some of its water and a compound of the formula $MgCl_2.9\ MgO.24\ H_2O$ remained. When the original compound was treated with boiling water and dried over SO_3 there was left a compound of the formula2 $MgO.3\ H_3O$. All of these compounds were hard and could not be disintegrated by boiling water. He also made a series of tests on the amounts of water lost at different temperatures by these three compounds and obtained the results shown in the following table:

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(1) Comptes Rended - vol. 65, page 102.

(2) Annalen der Chemie - vol. 159, page 341.

WATER LOST AT DIFFERENT TEMPERATURES.

$MgCl_2.9\ MgO.17\ H_2O$.	heated to	100°C	lost	9	mol. of water.
" "	" "	180°C	"	11	" " "
$MgCl_2.5\ MgO.24\ H_2O$	" "	100°C	"	9	" " "
" "	" "	180°C	"	14	" " "
$2\ MgO.3\ H_2O$	" "	100°C	"	2.1 %	" "
"	" "	180°C	"	4.3 %	" "

Krause[1] in discussi~~on~~ng Bender's work claimed that Bender's assumption of the formation of the normal anhydrous carbonate was incorrect, holding that because of the presence of an excess of the basic material it was much more probable that the basic carbonate would be formed. The formation of the basic carbonate would make Bender's results inaccurate.

Krause attempted to prevent the formation of the basic carbonate by the use of an excess of $MgCl_2$ solution. He treated the MgO with an excess of concentrated $MgCl_2$ solution, heated, shook, cooled and dried this, and obtained a solid of the composition $MgO.MgCl_2.16\ H_2O$.

Nuhman[2] separated a compound of the composition $Mg\frac{OH}{Cl}.5\ Mg(OH)_2$ He found that on long treatment with boiling water some of the $MgCl_2$ went into solution, leaving a chloride of the composition of Brucite.

In 1909 Robinson and Waggeman[3] published the results of a series of tests of mixtures of different concentrations of MgO

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(1) Comptes Rendes - vol. 94, page 444.

(2) Chemicher Zeitung - vol. 25, page 96.

(3) Journ. of Phys. Chem. - vol. 13, page 673.

and $MgCl_2$. These mixes were allowed to stand for six months at a temperature of 25°C, and then the liquid and precipitate were tested. They found the normal composition to be $3\ MgO, MgCl_2 . 10H_2O$.

In 1908 and 1909 there appeared a series of articles in the Chemicher Zeiting giving the results of several German researches on the composition of the magnesium oxychlorides.

Dr. Van Hoff[1] electrolyzed a concentrated solution of $MgCl_2$ and obtained at the cathode a white solid to which he gave the formula $MgCl_2 . 5\ MgO . 14\ H_2O$. On drying this over H_2SO_4 it lost three molecules of water, and on being dried to 180°C it lost eight molecules of water. He also made a mix of MgO and concentrated $MgCl_2$ and treated this vigorously with CO_2. In this way he hoped to get results in a short period of time comparable with with Bender's, in which the cement had been exposed to the CO_2 in the air for six months. He removed the excess $MgCl_2$ by washing with absolute alcohol and computed the formula to be:-
$MgCl_2 . 5\ MgO . 13\ H_2O$.

Kallenuer[2] objected to the analyses of the cement by treatment with cold water as had been done by Bender, and Van Hoff in several of his determinations. He claims that there is no doubt but that some of the combined $MgCl_2$ as well as the free chloride is removed by cold water. For this reason the results obtained by considering all of the $MgCl_2$ removed by the water as being uncombined are of little value. He concludes, from the fact that the chloride can be completly removed from the cement, leaving a hard residue, and from thermo-chemical data, which he was not

---

(1) Chemicher Zeitung - vol. 33, page 693.

(2) " " - vol. 33, page 871.

ready to give at present, that the cement is not an oxychloride at all, but is $Mg(OH)_2$ with $MgCl_2$ in solid solution.

Krieger[1] treated five grams of MgO with 200 c.c. of $MgCl_2$ solution of a specific gravity of 1.25, at room temperature. In two days time this gave a gelatinous mass. The excess chloride was removed by repeated extractions with absolute alcohol and the residue dried at 40°C. At the end of different time periods the mass was analysed and the following results were obtained:-

Time.	$MgCl_2$	MgO	H_2O
2 days.	1 part.	5.0 parts.	16.1 parts.
2 weeks.	1 "	3.3 "	10.2 "
4 weeks	1 "	2.0 "	8.9 "

At the end of four weeks time the composition of the compound remained constant, the formula being $MgCl_2.2MgO.9H_2O$. Krieger decided that since there were so many things which affected the cement, such as temperature, proportions of the ingredients, time of reaction etc. that no set formula could be given for Sorel cement. From the formulae given he evidently considered it to be an oxychloride of magnesia, and not a solid solution of $MgCl_2$ in $Mg(OH)_2$ as suggested by Kallenuer.

From the researches mentioned it would seem that Sorel cement is a magnesium oxychloride, having several molecules of water of crystallization. The exact proportions of the compound seem to depend on the conditions to which the cement has been exposed. It seems to have a formula approximating $MgCl_2.3MgO.10H_2O$.

(1) Chemicher Zeitung - vol. 34, page 246.

PHYSICAL RESEARCH ON MAGNESIA CEMENT.

The first investigator to publish any results on the physical properties of Sorel cement was Weber[1] in 1891. He studied the tensile strengths of different mixes of MgO and $MgCl_2$.He first made tests of MgO with different amounts of $MgCl_2$ solution of a constant density and found that beyond a certain proportion of $MgCl_2$ the strength decreased. His results on a series of tests were as follows:-

No.	MgO	$MgCl_2$ 6 aqu. 30 % sol.	Strengths (tensile)
1	10 pts.	6 pts.	1700 lbs./in^2
2	10	8	1300
3	10	10	1100
4	10	12	1000
5	10	14	860

			Water.	Ten. Str.
6	10	7	0 pts.	1468 lbs./in^2
7	10	6	1	1784
8	10	6	2	780
9	10	6	3	780

The tests recorded above show that the greatest tensile strength is obtained when a ratio of ten parts of MgO to six parts of $MgCl_2$(30 % solution) is used. The last three test show that the addition of water decreases the strength greatly. He also found that a small amount of water was given off at 100°C and not more than 70 % was given off at 200°C. Dr. Weber concluded from these tests that water alone could not be used for making a cement with MgO. He also found that $MgCl_2$ dissolved in absolute

(1) Scientific Amer. Sup. May 16,1891.

alcohol will react with MgO and set into a cement.

Schmidt made some tests on a mixture of one part by weight of anhydrous $MgCl_2$ and three parts by weight of MgO. He found that this absorbed moisture from the air indefinitely and became moist and soft. He made the statment which has often been repeated by users of magnesia cement that" It is desirable in testing the materials that a definite testing process should be adopted and the analysis of the magnesite should show MgO, H_2O of hydration, and CO_2.

Since the summer of 1912 the Materials Testing Laboratory of the University of Wisconsin has been making tests on Sorel cement.

The first tests were tension and compression tests of neat, 1 to 6 standard Ottawa sand, and floor mixes. The floor mixes were cement, sawdust, asbestos fibre, and iron oxide coloring. The results of the tests were not at all consistent. Tension and compression tests made by different operators at different times failed to agree, while tests made by different operators at the same time checked fairly closely. The reason for this lack of uniformity was laid to the differences in the moisture content of the air in the storage room at different times, it having been found that the moisture in the air had a great effect on the neat and the sand mixes, and a less effect on the floor mix.

Tests were made on several cements to determine the effects of different storage conditiond. The following storage mediums were tried:

1. Air where the relative humidity was rarely over 60 %
2. " " " " " averaged 90 %

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(1) Tonind. - vol. 35 page 673.

3. In $MgCl_2$ solution, specific gravity of 1.20
4. In kerosene.
5. In a dessicator over $CaCl_2$.
6. In running water.
7. In machine oil.
8. Shellaced and stored in air, relative humidity 60 %

The tests showed that for the neat mixes the best strength and the most uniform results were obtained in kerosene or machine oil storage.

For the 1 to 3 Ottawa sand mixes the kerosene, dessicator, machine oil, and dry air gave about the same results as to strength and uniformity.

The floor mixes showed the best strength with dry air or dessicator storage, with kerosene oil and machine oil second. The most uniform results were obtained in dry air,kerosene, or machine oil.

The 1 to 3 Ottawa sand averaged over 900 lbs./squ. in. tensile strength, and the floor mixes often averaged over 700 lbs. per square inch in tension.

SUMMARY.

As has already been stated it is the desire of the users of the magnesia cement to have the material standardized so that a desired result can be obtained by exact specification of raw materials, proportions etc..One manafacturer has stated the problem in the following words:-

" We are greatly interested in bringing this material to such a position that when properly calcined magnesite, so ground as to eliminate the possibility of dead burned magnesite portions creeping into parts of the shipments, is mixed with other binding and filling materials of proven value that definitely known results may be accomplished - - - "

Another manafacturer in speaking of proposed tests on composition floorings using magnesia cement said:

" The object of these tests is to standardize Composition flooring and to make available to the architect and builder and in fact, any user of the material, the necessary facts as to the composition and quality of the material so as to enable him to specify them in a clear concise manner."

The tests or data which would be needed in order that such specifications might be made can be classified under the following heads:

1. RAW MATERIALS.

(a) The cement: The amount of impurities in the cement and their effect on the floor. The determination of the dead burnt MgO in the cement. An accurate, quick and standard method for this determination would be of great use to the user of calcined

magnesite.

(b) The magnesium chloride: The tests would include a chemical analysis, giving the impurities in the $MgCl_2$ and a specific gravity determination of the solution strength, if the $MgCl_2$ is furnished in water solution.

(c) The fillers: It would be necessary to know the effects of different aggregates on the properties of the floor. These effects may be physical, affecting such properties as strength and resiliency, or they may be chemical affecting the reaction between the MgO and the $MgCl_2$.

2. PROPORTIONS OF INGREDIENTS USED.

The first thing to be done would be to establish the ratio of $MgCl_2$ to active MgO which would give the best results. After this had been done the proportions of $MgCl_2$, MgO and different filling materials for various types of floors could be determined. The density of $MgCl_2$ solution under different temperature conditions to give the best results would have to be determined.

3. PHYSICAL TESTS.

The effects of the variance of the many factors given above would have to be measured by physical tests. It would have to be decided which of the physical tests showed the "best" results. Tensile strength would be no indication of a good flooring material if at the same time the floor had a large coeffecient of expansion in setting. In general the tests which might be of value are:- tensile and compressive strength tests; heat conductivity; expansion and contraction in setting and after having thoroughly set; the thermal coeffecient of expansion; resiliency and abrasion tests.

It can be seen from the general outline given above that there are many problems to be solved in the standardizing of magnesia cement. Several of the manafacturers have been working on them in their own laboratories. Some tests have been made and published by individual workers. The Materials Testing Laboratory of the University of Wisconsin has been at work on magnesia cement for several years. Some of the results obtained have been summarized above, while the tests made during the year 1915 to 1916 are described in the second part of this thesis.

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PART TWO

THE EXPERIMENTAL WORK

The Object of the Tests.

The primary object of the experimental work was the determination of the effects on the physical properties of the cement of varying the quantity and density of the magnesium chloride solution used in the mix. Since the change in volume of the cement in setting is one of the important factors determining its fitness for use as, especially as a flooring, particular attention was paid in these tests to the expansion in setting of the various mixes.

An outline of the tests made and their objects is given below:

1. Preliminary Expansion Tests.

Object: to determine the comparative changes in volume in setting of neat, 1 to 6 sand, and standard floor mixes.

2. Tests with Varying Quantities and Densities of $MgCl_2$ Solution.

(a) Expansion Tests.

Object: The determination of the effects of this variation on thechange in volume in setting.

(b) Tensile Strength Tests.

Object: The determination of the effects of this variation on on the tensile strength, and the determination of the relation, if any, between strength and constancy of volume tests.

(c) Cross Bending Tests.

Object: The determination of the modulus of rupture and the modulus of elasticity of the different mixes.

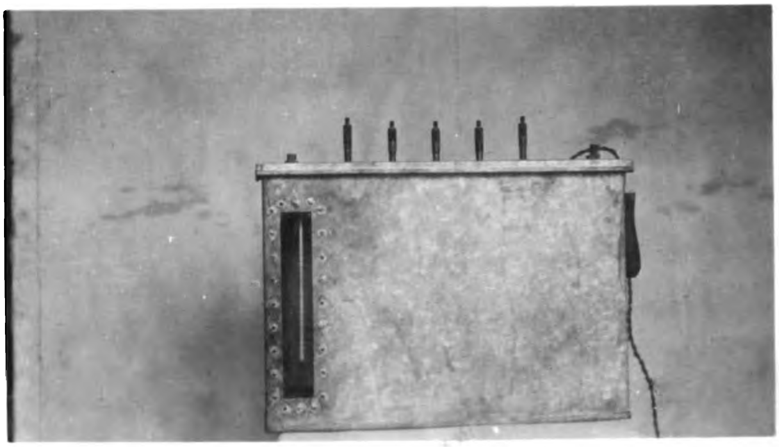


Fig. 1
Box, with micrometer frame
in place.

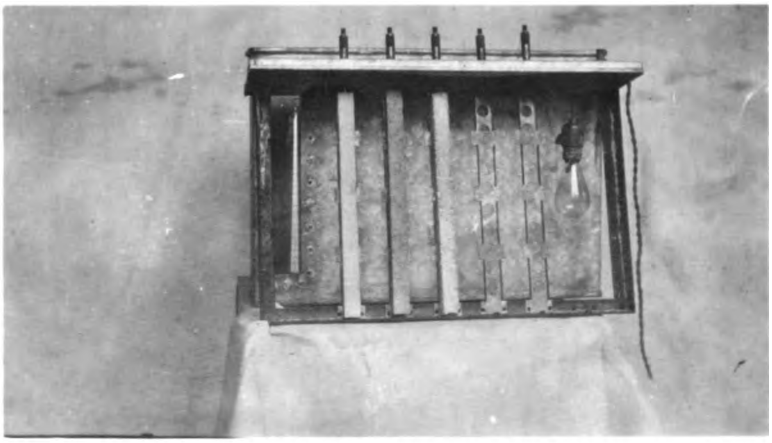


Fig. 2
Micrometer frame, with expansion specimens in it.

(d) Change in Weight in Setting.

Object: The determination in the changes in the water content in setting in a dry and a saturated atmosphere, and the determination of the relation between these changes and the changes in volume.

3. Expansion Tests with Different Cements.

Object: The determination of the relation between the change in volume in setting and the chemical constituents of the cements.

4. Test for Coeffecient of Thermal Expansion.

Object: The determination of the coeffecient of thermal expansion of the standard floor mix.

5. Expansion Test from Time of Molding.

Object: The determination of the expansion from the time the specimen was put in the mold in order to learn the effect of the elasticity of the aggregate on the initial expansion.

The Apparatus and Method of Procedure.

Materials: The calcined magnesites used for these tests were furnished the Materials Testing Laboratory by the American Monolith Company of Milwaukee Wisconsin. They were from different sources and of different chemical compositions. (See page 27 .) The magnesium chloride was also furnished by the American Monolith Company as a liquid of 22° Beaume strength and also in lump form. The lump magnesium chloride was made up to the desired strength with water from the tap.

The sawdust used for the floor mixes was maple sawdust. 88 % was retained on a No. 50 screen, having openings .011"square.

The asbestos was in the form of shredded asbestos fibres.

Expansion Tests.

The expansion in setting test consisted of testing a specimen 14" x 1" x 1". The dry materials, magnesite, sawdust etc. were first well mixed, then the liquid was added and the whole well mixed by hand for exactly 1¼ minutes. Immediately after the mixing the batch was placed in the oiled iron molds (14" x 1" x 1"). Small glass plates were placed in the ends of the specimens to provide smooth bearing surfaces. The specimens were stored in the open air while setting. At the end of the setting period, which varied for the tests, they were removed from the molds and placed in an upright metal frame so that the glass plate in the bottom rested against a fixed point, while a screw micrometer could be turned down against the plate on the top of the specimen.

After the specimen was in place the micrometer was turned down and the first or zero reading was taken. The micrometer was then turned up free of the specimen. At the end of the desired time period another micrometer reading was taken. The difference between the two readings was the change in length of the specimen during that time interval. Readings were taken at regular intervals usually 24 hour periods, until it was desired to stop the test, which was when a constant volume had been attained, or else the volume changes had become uniform. Data was taken for all tests on standard forms. (See page 28) The time - expansion curves were plotted from this data. Since all the specimens tested were of the same length the expansions in setting were not reduced to unit deformations but were plotted directly in inches.

The first test was made on different magnesites, using a standard floor mix. The standard mix is one suggested by the American Monolith Company, which was found by earlier workers

in the Materials Testing Laboratory to give the best results.

At first the expansion test was made in the open air of the laboratory where the humidity varied greatly. On plotting the time - expansion curves and the humidity curves for the same period of time it was noted that the expansion of the cement seemed to be a function of the humidity of the air in which it was stored.

In order to control the storage conditions during the expansion tests an air-tight galvanized iron box was made. (Sde page 20) The top of the box was removable, but when in place it was sealed by a heavy rubber gasket. It contained a frame and micrometers so that five specimens could be tested at once. A glass window was placed in the front side so that the interior temperature of the box could be read on a thermometer hung in front of the window. Every precaution was taken to make the box air-tight. An electric light globe was hung in the box so that, if desired, a temperature higher than that of the outside air could be obtained.in the box.

A dry atmosphere was secured in the box by placing in it four 3 inch evaporating dishes containing concetrated sulphuric acid. After the expansion readings with the specimen had been obtained in the dry atmosphere as long a time as seemed desirable the acid was removed and water substituted, giving a moist atmosphere in the box. The temperature in the box remained fairly constant thruout the tests.

Five mixes were usually tested for each set of tests. The composition of each mix was varied as desired for that particular test. One batch however was always of the "standard mix" mentioned above.

Change in Weight in Setting.

In the last three tests cylinders 2" by 1" in diameter were made up from each batch, weighed and placed in the test box with their respective expansion specimens. They were weighed again when the acid was removed, and when the test was discontinued. The changes in weight gave the weight of the water lost in the dry atmosphere and the water gained in the saturated atmosphere.

Cross Bending Tests.

Two 14" x 1" x 1" specimens weremade up from each batch. One was placed in the expansion test frame as described above, and the other was stored in air. At the end of the expansion test both wdre subjected to a cross bending test. The test was made in an Olsen Cross Bending Machine; a 12" span being used. The load was applied in the middle; and deflection readings were taken every 0.02" until failure. The data from these tests was used in determining the modulus of rupture and the modulus of elasticity.

Tensile Tests.

Four standard tensile briquettes were made up from each batch, stored in air, and tested in a standard Riehle' testing machine at the same time the cross bending tests were made.

Coeffecient of Thermal Expansion.

Tests were made to determine the coeffecient of thermal expansion of standard floor mixes. The tests were made on the 14" x 1" x 1" specimens. One end of the specimen was held against a fixed block; a travelling micrometer microscope was focused on a mark on a rivet set in the other end of the specimen. The lower temperature was obtained by covering the specimen with cold oil. The oil bath was heated to 100°C. for the higher temperature. The expansion through this temperature range was measured by the travelling micrometer.

Expansion from Time of Molding Test.

A test was made of expansion immediately after molding. The specimen was put in the mold, and placed flat on the table. The regular expansion specimen was used. A small metal rivet with a mark on it was placed on the top side near one end of the specimen and the travelling micrometer microscope was focused on this mark. The other end of the specimen rested against a fixed block. Readings were taken from the time the specimen was placed in the mold.

ANALYSES OF CEMENTS.

Cem't No.	SiO_2	Fe and Al_2O_3	CaO	MgO	SO_2	Loss on ignition
22	4.84%	.46%	3.58%	86.44%	0.0%	4.95%
33	3.39	.70	2.67	86.78	0.0	6.79
44	3.88	.42	17.08	56.11	0.0	21.91
6	.68	.66	19.07	66.45	1.31	12.82
7	2.08	.61	3.00	81.03	.36	12.84
8	3.52	.66	2.97	86.37	.24	6.25
N I	2.74	.28	3.03	91.76	trace	1.57
N2	5.14	.32	4.76	82.95	"	6.07
5	7.84	1.24	1.62	77.87	0.0	11.90

NOTES ON DATA AND CURVES.

The Storage.

The storage is indicated as whether in the dry ar saturated atmosphere of the box, or in the open air.

Expansion Tests.

The time increments are given in hours. The zero reading was taken when the specimens were placed in the box. The expansion increments are the actual expansions in inches of each 14 inch specimen. The first micrometer reading was taken as the base for computing the increments in the dry atmosphere. Another base reading was taken after the water was added and the increments from that time are computed using this as the zeri reading. This is done because there always was some shifting of the specimens due the removal of the frame for the addition of the water.

Tensile Tests.

The values given are the averages of the four test briquettes. If any briquette fell more than a 100 pounds below the average it was not used in computing the values given.

Cross Bending Tests.

The deflections are the center deflections. When possible the deflection at failure was obtained. If this was not obtained the load at failure is placed opposite thedeflection marked (?).

In computing the modulus of rupture the formula: $S = \frac{Mv}{I}$ was used. The values obtained for the two specimens were averaged and the average is reported on the data sheet.

The modulus of elasticity was computed from the formula: $E = \frac{Pl}{48 I y}$. The deflection taken was the maximum deflection that was recorded.

Test No. N 1

Batch No. 1

UNIVERSITY OF WISCONSIN

LABORATORY FOR TESTING MATERIALS

TESTS ON MAGNESIA CEMENT

22 Cement 528 gr.

Sawdust 312 gr.

Asbestos 144 gr.

95/100 Mg Cl 835 cc.

Put in Molds

Taken out

Storage

Operator

Density

Remarks:-

Results

Expansion						
Date	Time	Mic.	Temp.	Remarks	Inc. Time	Inc. Mic.
3/11/16	9:00 A	.5328	76			
4/11/16	9:00 A	.5928	76		24	.0200

Tension

No.	Tension Strength	Age

Cross Bending

No.	Deflection	Load

Abrasion

No. ___ Rev. ___ No. ___ Rev. ___

Init. Wt.

Final Wt.

Loss

Init. Wt.

Final Wt.

Loss

TEST NUMBER N 1 .

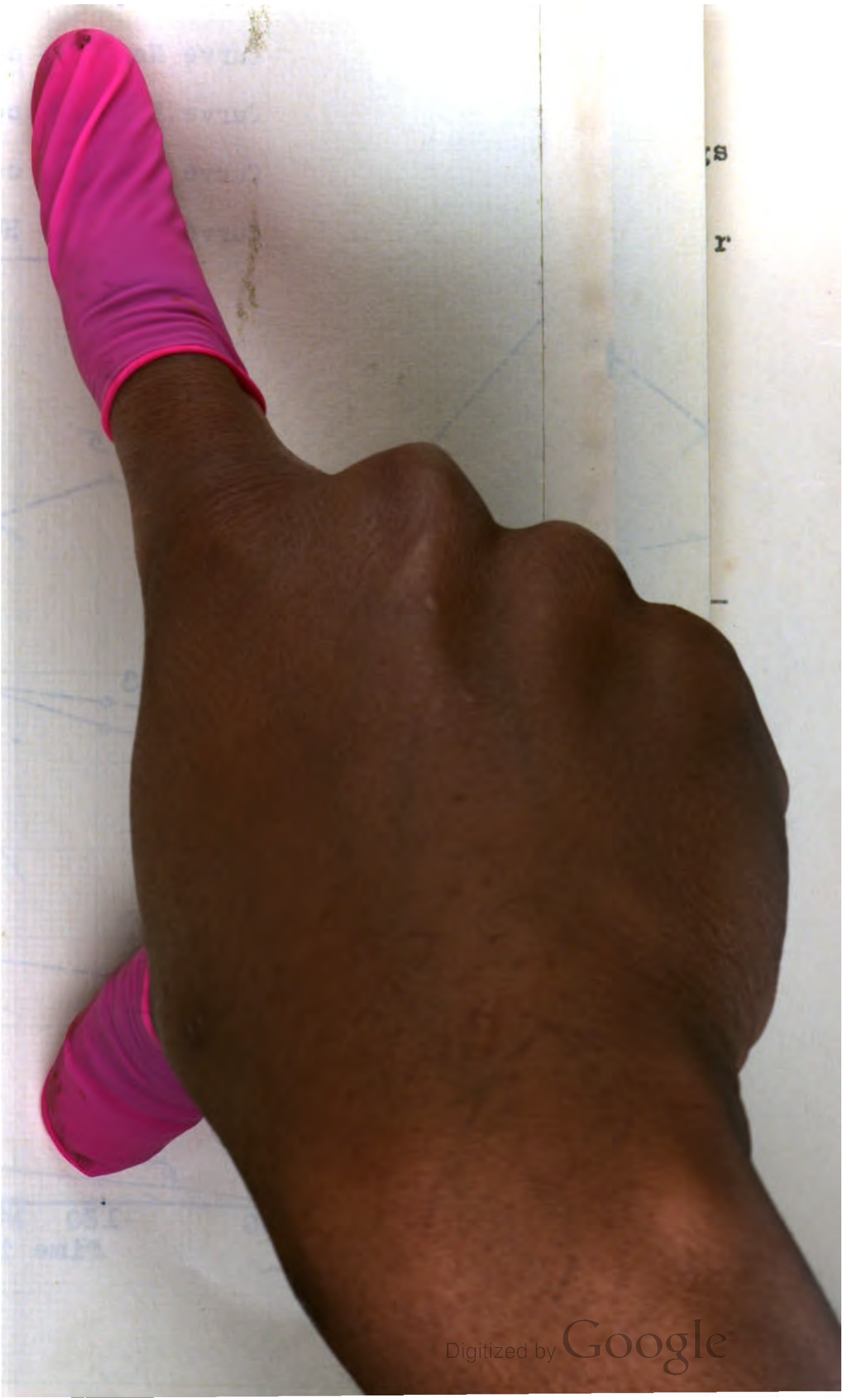
Average temperature 60°F
Storage - air
Time in molds 5 hrs.

Object of test:-
Expansion in setting of different cements.

Composition	BATCH NUMBER I	II	III	IV
Cement Number	33	8	44	22
Cement (grams)	264	264	264	264
Sawdust (grams)	156	156	156	156
Asbestos (grams)	72	72	72	72
Coloring (grams)	43	43	43	43
$MgCl_2$: C.C.	455	455	455	455
: : :Density	1.20	1.20	1.20	1.20

Humidity	Time	Expansion Test (increments)			
56 %					
56	4 hrs.	.0315in.	.0165in.	.0025 in.	
56	18	.0424	.0402	.0130	
46	40	.0433	.0420	.0390	start
41	50	.0405	.0413	.0408	.0087in.
42	65	.0367	.0405	.0408	.0118
48	89	.0295	.0354	.0392	.0184
51	103	.0270	.0330	.0380	.0204
61	127	.0225	.0288	.0362	.0223
46	155	.0120	.0155	.0270	.0183
51	179	.0130	.0170	.0280	.0002
44	244	.0157	.0232	.0312	.0014
77	292	.0174	.0250	.0318	.0037
55	340	.0156	.0243	.0314	.0046
43	436	.0073	.0091	.0230	.0038
41	460	.0076	.0096	.0230	-.0043
41	772	.0045	.0050	.0192	-.0040

No. N1



TEST NUMBER N2

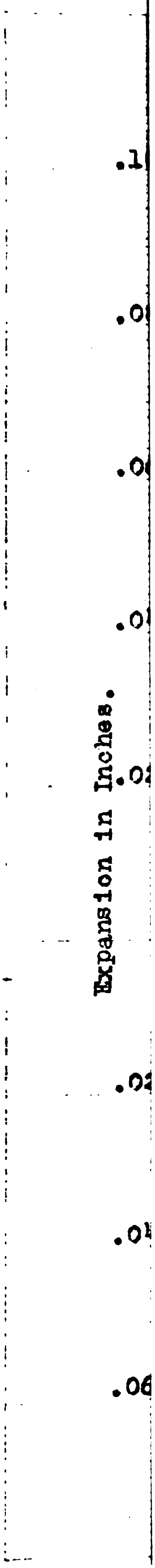
Cement No.22,33,44,and 8.
Average temperature 72°F
Storage - Dry -
Time in molds - 7 hours.

Object of test:-
Expansion in setting of different cements.

Composition	Batch Number I	II	III &	IV *	V
Cement No.	22	33	8		44
Cement grs.	528	528	528		528
Sawdust grs.	312	312	312		312
Asbestos grs.	144	144	144		144
$MgCl_2$: c.c.	760	760	760		760
: density	I.20	1.20	1.20		1.20
Time inc.		Expansion test (increments)			
2hrs.	.0090in.	.0155in.	.0163in.	.0090in.	no
4	.0171	.0250	.0300	.0165	readings
18	.0183?	.0333	.0423	.0315	taken.
44	.0340	.0340	.0426	.0060	Loose
68	.0345	.0290	.0408	-.0047	microm'r
92	.0310	.0265	.0378	-.0400 ?	
120	.0263	.0195	.0312	-.0275	
138	.0240	.0157	.0298	-.0330	
164	.0215	.0117	.0180	-.0384	
188	.0190	.0074	.0141	-.0403	
216	.0150	.0021	.0088	-.0430	
236	.0132	-.0008	.0029	-.0490	
259	.0120	-.0027	.0008	-.0456	
284	.0125	-.0036	-.0019	-.0415	
306	.0110	-.0041	-.0028	-.0424	
331	.0110	-.0036	-.0057	-.0380	
Tensile str. in lbs per square inch.		Tensile Strengths (28 days)			
	865	890	670		787
Deflection		Cross Bending test.			
Box .02in.	44lbs.	44 lbs.	20 lbs.		36 lbs.
.04	76	70	47		56
.05					60 ult.
.06					
.07	104 ult.				
?		72 ult.	50 ult.		
Air .02in	35	40		32	28
.04	60	66		64	48
.05		96 ult.		76 ult.	
.06	80 ult.				66 ult.
Mod. of Rup.	1650	1520	900	1370	1135
Mod. of Elas.	596,000	800,000	511,000	660,000	498,000

*Note. Specimen No. IV had air storage for expansion readings. All others were taken in dry box atmosphere.

No. N2



TEST NUMBER N5

Cemmt Number 22
Average Temperature 80°F
Storage - Dry - Saturated
Time in molds - 20 hrs.

Object of test:-
Expansion in setting
of neat, sand, and
floor mixes.

Composition:-	BATCH NUMBER I	II	III
Cement grs.	1000	212	176
Sand grs.		1272	
Sawdust grs.			104
Asbestos grs.			48
$MgCl_2$: c.c.	550	178	278
:density	1.20	1.20	1.20

Expansion test (increments)

Specimen No.	IA	IB	IIA	IIB	III
Time 4hrs.	.0379in.	.0351in.	.0091in.	.0076in.	.0144
23	.0471	.0430	.0107	.0076	.0096
25	.0464	.0423	.0103	.0071	.0084
49	.0403	.0381	.0088	.0053	-.0076
74	.0392	.0355	.0079	.0043	-.0153
97	.0369	.0327	.0071	.0034	-.0208
146	.0340	.0292	.0061	.0028	-.0272
172	.0313	.0276	.0055	.0023	-.0293
197	.0304	.0258	.0052	.0018	-.0307
216	.0295	.0250	.0052	.0018	.0318
Water added					
240	.0131	.0128	.0077	.0086	.0241
264	.0297	.0290	.0140	.0160	.0318
312	.0933	.0873	.0272	.0243	.0375
336	.1143	.1050	.0300	.0257	.0371*
360			.0318	.0269	.0368*
384			.0350	.0293	.0388

* Note:- The water in the box had all been absorbed, more water being added at this point. Readings marked (*) were for this reason not plotted.

No. N5

TEST NUMBER N6

Cement No. 22
Average Temperature 63°F
Storage - Dry - Saturated
Time in Molds - 21 hrs.

Object of test:- Expansion with a constant liquid content and varying density.

Composition:-	BATCH NUMBER I	II	III	IV	V
Cement grs.	528	528	528	528	528
Sawdust grs.	312	312	312	312	312
Asbestos grs.	144	144	144	144	144
$MgCl_2$:c.c.	836	836	836	836	836
:density	1.27	1.23	1.20	1.15	1.05
Time inc.	**Expansion test (increments)**				
11	.0163	.0159	.0167	.0111	Too soft to test.
22	.0222	.0211	.0212	.0148	
46	.0294	.0261	.0252	.0197	
70	.0313	.0280	.0264	.0211	
94	.0321	.0284	.0262	.0202	
120	.0329	.0285	.0253	.0174	
142	.0329	.0280	.0238	.0142	
172	.0328	.0264	.0203	.0098	
190	.0325	.0260	.0184	.0064	
214	.0322	.0241	.0155	.0020	
238	.0320	.0223	.0122	.0000	
262	.0310	.0189	.0065	-.0021	
282	.0307	.0179	.0051	-.0029	
water added					
330	.0078	.0109	.0145	.0186	
336	.0080	.0121	.0153	.0191	
355	.0112	.0145	.0179	.0208	
378	.0140	.0169	.0201	.0225	
403	.0172	.0190	.0219	.0238	
Tensile str. in lbs. per square inch.	**Tensile Strengths (21 days)**				
	839	554	496	225	50
Deflection	**Cross Bending tests.**				
Box .02	40 lbs.	30 lbs.	34 lbs.	18 lbs.	No tests made.
.04	60 ult.	50 ult.	50	36 ult.	
.05			66 ult.		
?					
Air .02	32	30	24	12 lbs. ult.	
.04	70	74	24 ult.		
.05	76 ult.	87 ult.			
?					
Mod. of Rup.	1225	1215	990	470	
Mod. of Elas.	653,000	670,000	523,000	324,000	

No. N6

TEST NUMBER N9

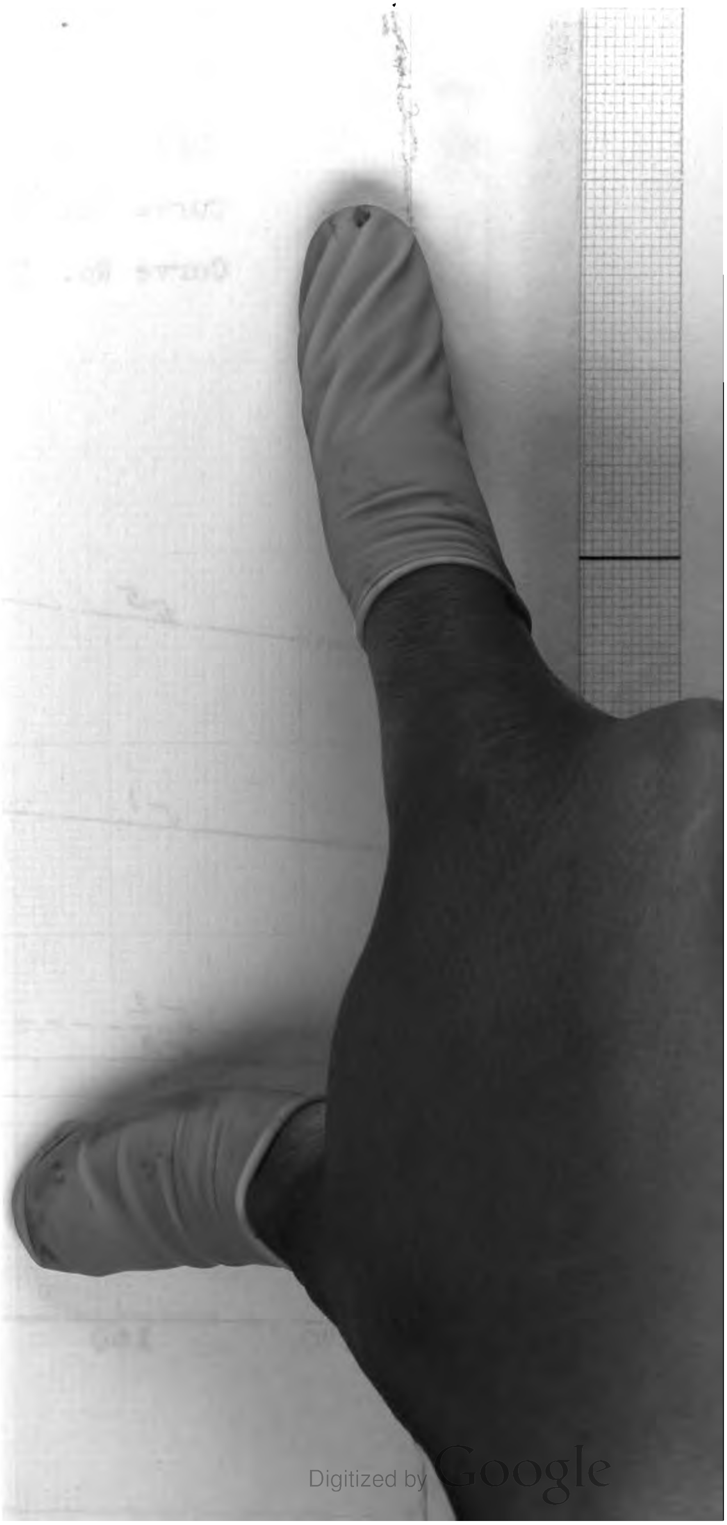
Cement No. N2
Average temperature 63°F
Storage - Dry - Saturated
Time in molds - 48 hrs.

Object of test:-
Expansion with a constant liquid content and varying density.

	BATCH NUMBER				
Composition:-	I	II	III	IV	V
Cement grs.	528	528	528	528	528
Sawdust grs.	312	312	312	312	312
Asbestos grs.	144	144	144	144	144
$MgCl_2$:c.c.	836	836	836	836	836
:density	1.27	1.23	1.20	1.15	1.10
Time inc.	Expansion test (increments)				
5 hrs.	.0031in.	.0023in.	.0035in.	.0040in.	*.0068in.
25	.0115	.0072	.0078	.0075	.0176
48	.0163	.0100	.0108	.0090	.0224
80	.0213	.0128	.0132	.0102	.0283
97	.0231	.0140	.0140	.0110	.0307
119	.0245	.0148	.0138	.0118	.0340
173	.0269	.0160	.0138	.0120	.0384
199	.0273	.0163	.0131	.0118	.0394
212	.0283	.0165	.0116	.0113	.0418
240	.0293	.0166	.0111	.0110	.0430
water added					
288	.0117	.0074	.0039	.0018	.0024
336	.0229	.0128	.0066	.0030	.0054
384	.0325	.0188	.0096	.0044	.0088
Tensile strength in lbs,. per square in.	Tensile Strengths (19 days)				
	853	590	634	442	92
Deflection	Cross bending tests				
Box.02 in	28 lbs.	36 lbs.	22 lbs.	22 lbs.	10 lbs.
.04	50	52 ult.	48	46 ult.	
.05	56 ult.		50 ult.		
Air.02	42	32	36	30	6 lbs.
.04	70	66	62	46 ult.	
.05	72 ult.	71 ult.	76 ult.		
Mod. of Rup.	1150	1100	1135	830	144
Mod. of Elas.	555,000	637,000	680,000	497,000	?
Loss in H_2SO	1.17%	3.21%	7.60%	10.7%	9.35%
Gain in H_2O	5.80%	3.46%	2.53%	3.00%	2.19%

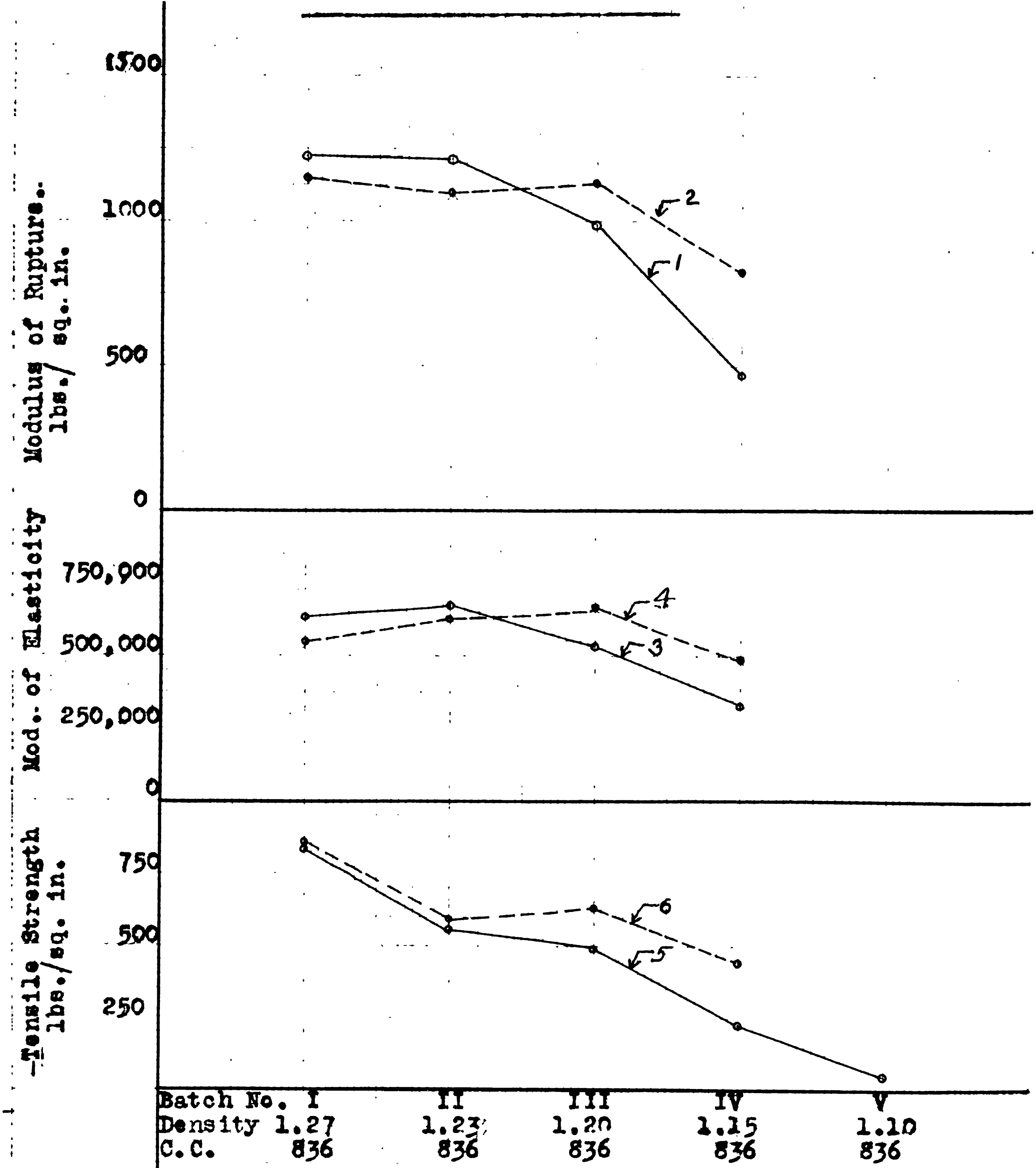
* Note:- Top bearing glass was loose.

No. 49



STRENGTH - CURVES

Curve No. 1 - Test No. N6 - Modulus of Rupture.
Curve No. 2 - Test No. N9 - " " "
Curve No. 3 - Test No. N6 - Modulus of Elasticity.
Curve No. 4 - Test No. N9 - " " "
Curve No. 5 - Test No. N6 - Tensile Strength.
Curve No. 6 - Test No. N9 - " "



TEST NUMBER N7

Cement No. 22
Average Temperature 67°F
Storage - Dry - Saturated
Time in molds - 19 hrs.

Object of test:-
Expansion with a constant density and a varying liquid content.

Composition:-	I	II	III	IV	V
	BATCH NUMBER				
Cement grs.	528	528	528	528	528
Sawdust grs.	312	312	312	312	312
Asbestos grs.	144	144	144	144	144
$MgCl_2$: c.c.	580	721	835	935	1080
:density	1.20	1.20	1.20	1.20	1.20

Time inc.	Expansion test (increments)				
4 hrs.	.0139in.	.0135in.	.0117in.	.0094in.	.0072in.
8	.0184	.0216	.0199	.0183	.0132
24	.0218	.0303	.0309	.0286	.0226
47	.0225	.0354	.0357	.0334	.0267
71	.0197	.0376	.0407	.0382	.0302
95	.0178	.0374	.0415	.0394	.0315
119	.0172	.0359	.0415	.0400	.0324
143	.0163	.0356	.0415	.0404	.0333
168	.0156	.0342	.0409	.0404	.0334
192	.0149	.0330	.0404	.0399	.0333
water added					
240	.0404	.0208	.0090	.0094	.0051
264	.0523	.0268	.0143	.0112	.0063
288	.0624	.0330	.0176	.0133	.0075
312	.0719	.0384	.0213	.0152	.0088
336	.0804	.0440	.0249	.0175	.0103
360	.0876	.0492	.0277	.0194	.0115
384	.0928	.0533	.0301	.0208	.0121

Tensile str. in lbs. per square inch.	Tensile Strengths (16 days)				
	240	487	762	739	572

Deflection	Cross Bending Tests				
Box .02	10 lbs.	22 lbs.	28 lbs.	28 lbs.	20 lbs.
.04		32 ult.	46 ult.	44	22 ult.
.05				50 ult.	
Air .02	16 lbs.	26	32	36	20
.04		40 ult.	60	60	48
.05			68 ult.	68 ult.	60 ult.

Mod. of Rup.	250	650	1025	1060	740
Mod. of Elas.	432,000?	390,000	524,000	510,000	379,000

12

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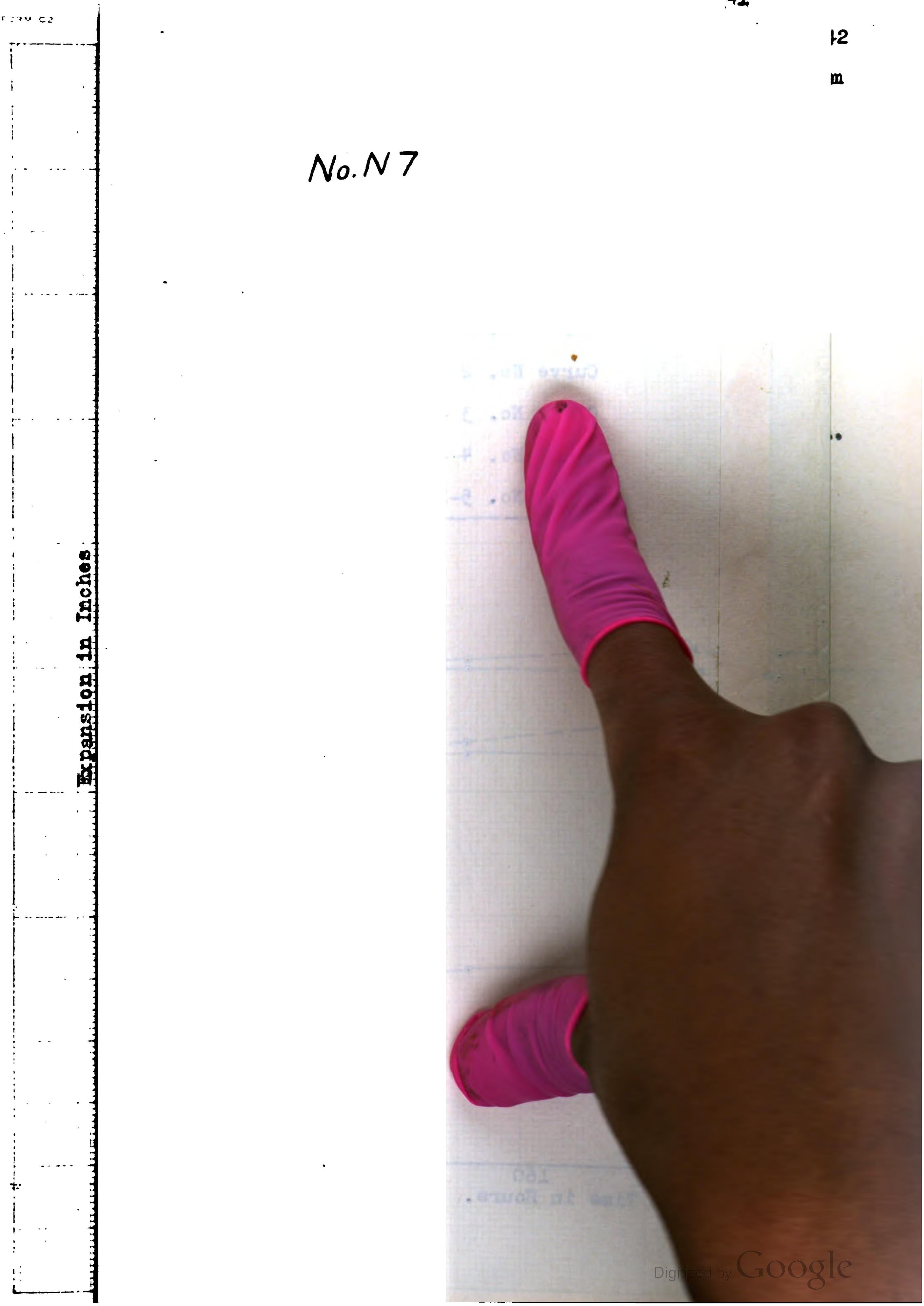
No. N7



TEST NUMBER N8

Cement No. N2.
Average Temperature 65° F.
Storage - Dry - Saturated
Time in Molds - 24 hrs.

Object of test:-
Varying the Magnesium chloride content at a constant density.

BATCH NUMBER.

	I	II	III	IV	V
Compostion:-					
Cement - - - -	528 gr.	528 gr.	528 gr.	528 gr.	528 gr.
Sawdust - - - - -	312 "	312 "	312 "	312 "	312 "
Asbestos - - -	144 "	144 "	144 "	144 "	144 "
$MgCl_2$:Density-	1.20	1.20	1.20	1.20	1.20
: c.c. -	580	721	835	935	1080

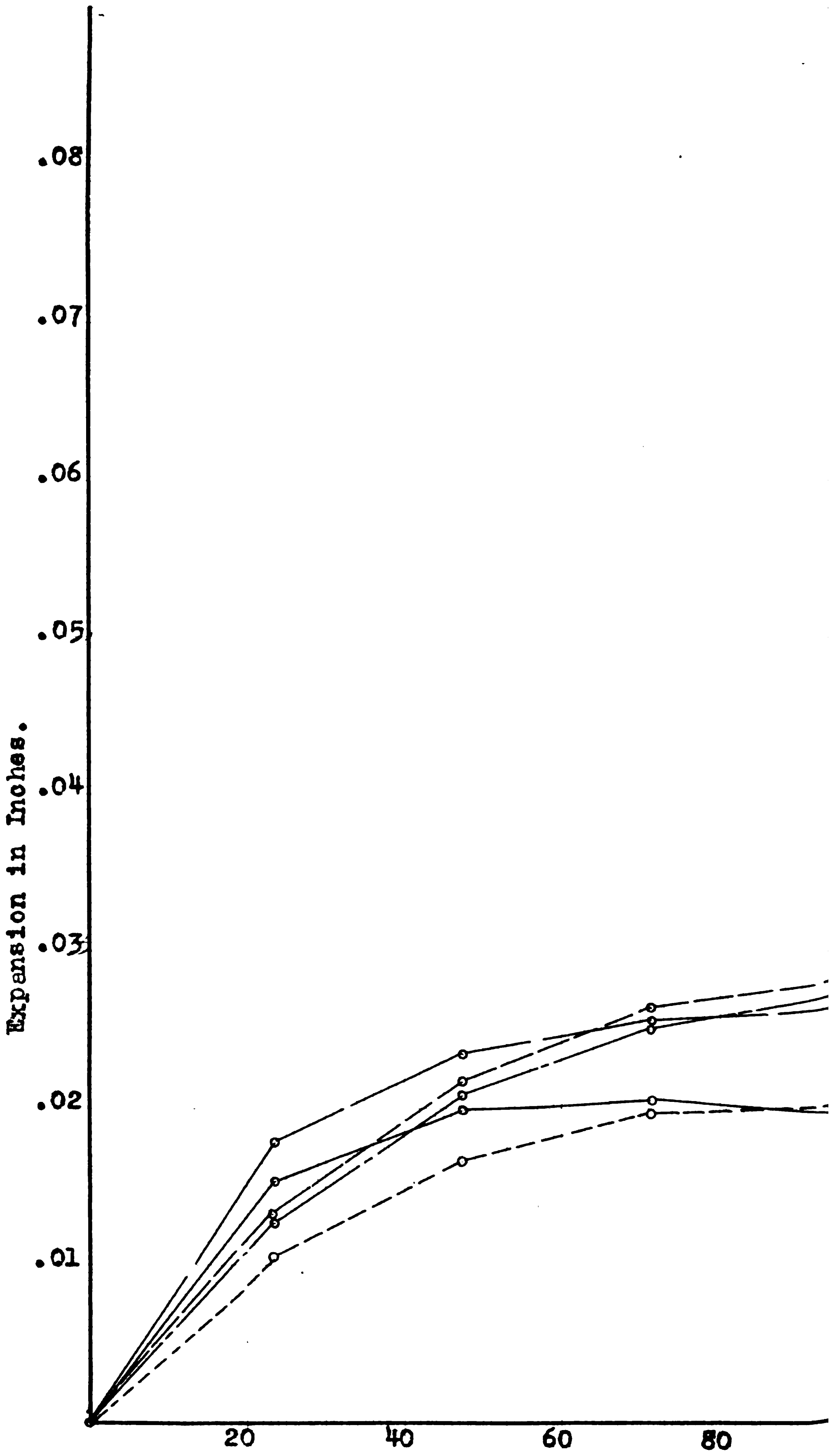
Time	Expansion Test (increments)				
23 hrs.	.0151in.	.0104 in.	.0176in.	.0136in.	.0133in.
47	.0195	.0164	.0233	.0216	.0210
71	.0202	.0194	.0254	.0258	.0249
95	.0191	.0199	.0263	.0278	.0269
119	.0175	.0195	.0274	.0291	.0285
143	.0162	.0188	.0279	.0301	.0293
190	.0127	.0159	.0274	.0305	.0301
214	.0104	.0143	.0267	.0306	.0304
238	.0095	.0119	.0260	.0305	.0305
263	.0079	.0106	.0254	.0301	.0306
water added.					
287	.0110	.0009	.0015	.0019	.0026
312	.0184	.0099	.0028	.0041	.0044
359	.0278	.0155	.0073	.0074	.0075
383	.0306	.0178	.0090	.0087	.0088
407	.0331	.0204	.0110	.0108	.0108

Tensile Strength Test (22 days)

Tensile str.	337 lb/in.	582 lb/in	718 lb/in	738 lb/in	592 lb/in

Cross Bending Tests

Deflection					
Box .02 in.	20 lb.	26 lb.	34 lb.	13 lb.	20 lb.
.04	26 ult.	46	52	32	40
.06		52 ult'	55 ult.	50 ult.	44 ult.
Air .02	20	24	30	38	30
.04	26 ult.	47	62	70	52 ult.
.06		50 ult.	70 ult.	85 ult.	
Mod. of Rup.	470	920	1120	1210	865
Mod. of Elas.	280,000	502,000	615,000	480,00	495,000
Loss in H_2SO	4.5 %	7.8%	9.2	10.5%	11.3%
Gain in H_2O	2.9%	2.9%	2.9%	3.8%	5.0%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Expansion in Inches.
20
40
60
80

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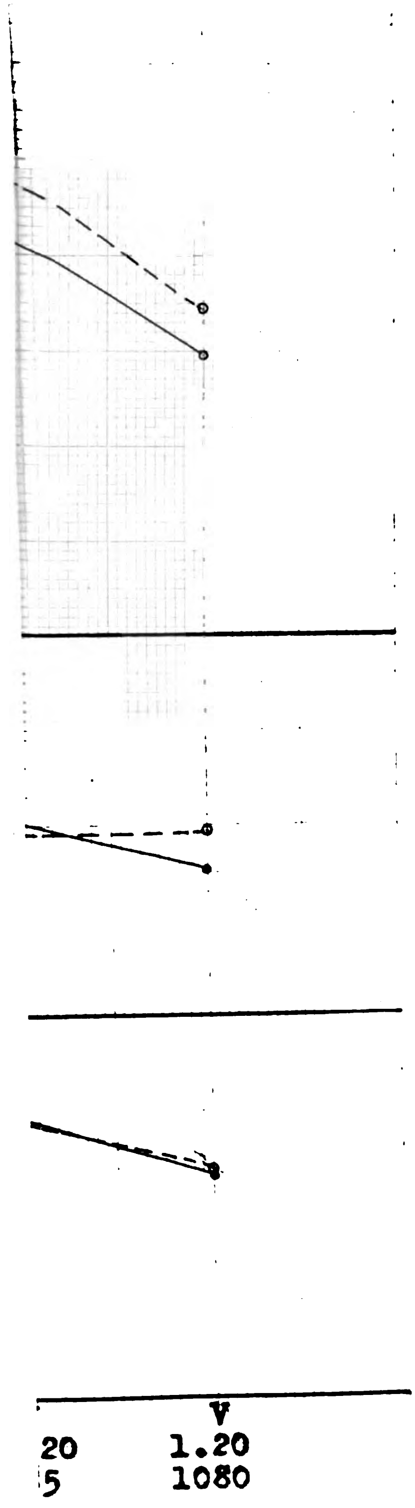
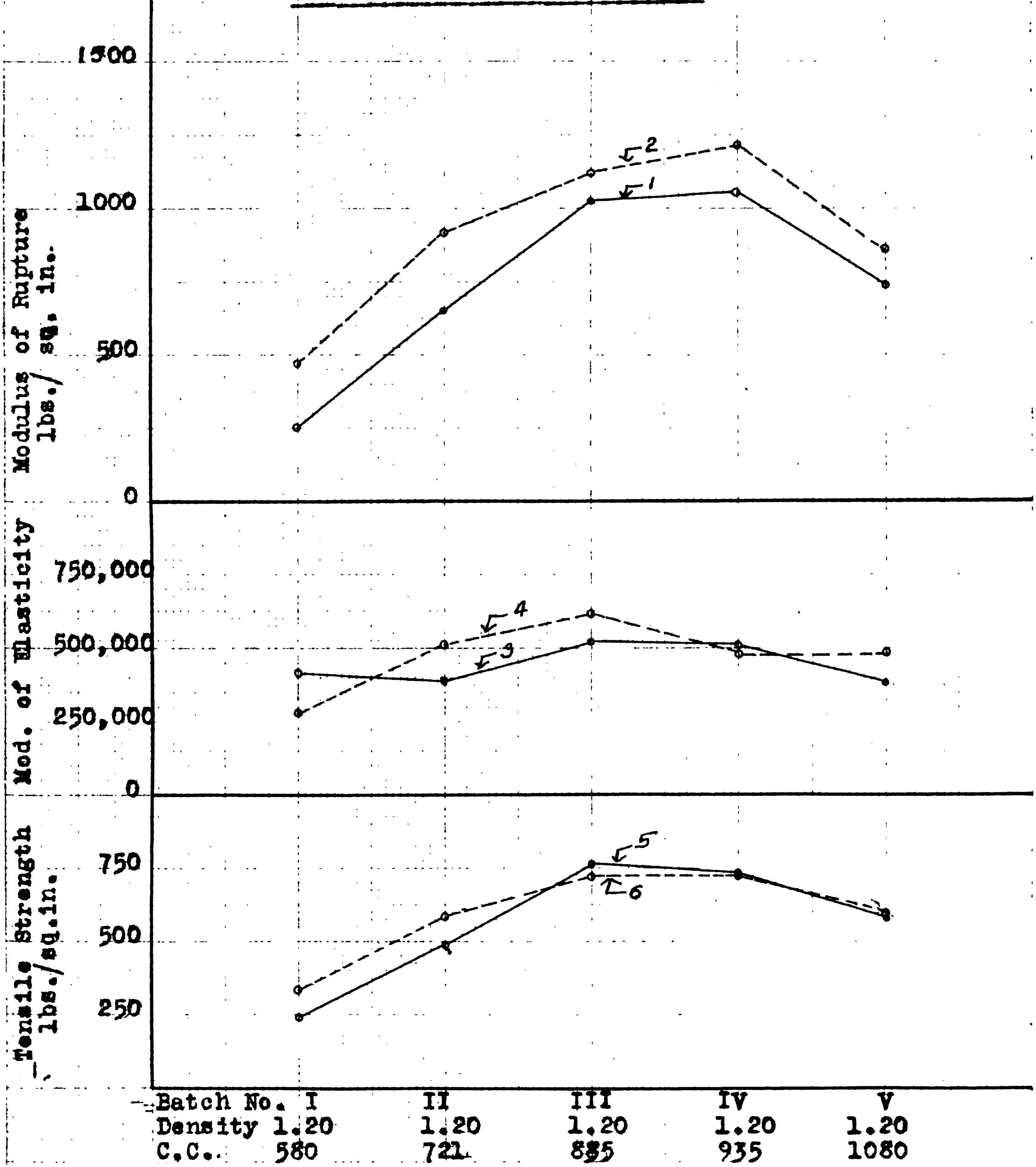


Na N8

STRENGTH — CURVES

Curve No. 1 - Test No. N7 - Modulus of Rupture.
Curve No. 2 - Test No. N8 - " " "
Curve No. 3 - Test No. N7 - Modulus of Elasticity.
Curve No. 4 - Test No. N8 - " " "
Curve No. 5 - Test No. N7 - Tensile Strength.
Curve No. 6 - Test No. N8 - " "



TEST NUMBER N3

Cement Number 22
Average Temperature 80°F
Storage - Dry - Saturated
Time in molds - 23 hrs.

Object of test:-
Constant $MgCl_2$ content at a varying density..

Composition:-	Batch Number I	II	III	IV	V
Cement grs.	528	528	528	528	528
Sawdust grs.	312	312	312	312	312
Asbestos grs.	144	144	144	144	144
$MgCl_2$: c.c.	385	454	588	695	795
: density	1.31	1.28	1.23	1.20	1.18

Time inc.	Expansion test (increments)				
23	.0388in.	.0186in.	.0175in.	.0188in.	
47	.0180	-.0063	-.0131	-.0017	.0166in.
71	-.0089	-.0231	-.0275	-.0104	.0047
95	-.0240	-.0366	-.0373	-.0232	-.0148
119	-.0345	-.0451	-.0441	-.0275	-.0148
143	-.0401	+.0482	-.0484	-.0304	-.0180
191	-.0476	-.0569	-.0574	-.0340	-.0200
215	-.0485	-.0581	-.0583	-.0350	-.0226
239	-.0495	-.0591	-.0590	-.0357	-.0233
H_2O added					
263	.0589	.0448	.0687??	.0224	.0110
270	.0684	.0525	.0397	.0268	.0192
287	.0881	.0651	.0479	.0310	.0240
311	.1068	.0771	.0555	.0358	.0271

Tensile str. in lbs. per square inch.	Tensile Strengths (14 days)				
	101	176	330	372	405

Deflection	Cross Bending test				
Box .02 in.	8 lbs.	18 lbs.	21 lbs.	22 lbs.	26 lbs.
.04		24 ult.	30 ult.	41	46
.05				42 ult.	
?					48 ult.
Air .02 in.		16	17	22	26
.04		24 ult.	18 ult.	42	34 ult.
.06				47 ult.	
?	4 ult.				
Mod. of Rup.	144	396	750	800	740
Mod. of Elas.	173,000	240,000	260,000	350,000	442,000

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No. N3

TEST NUMBER N10

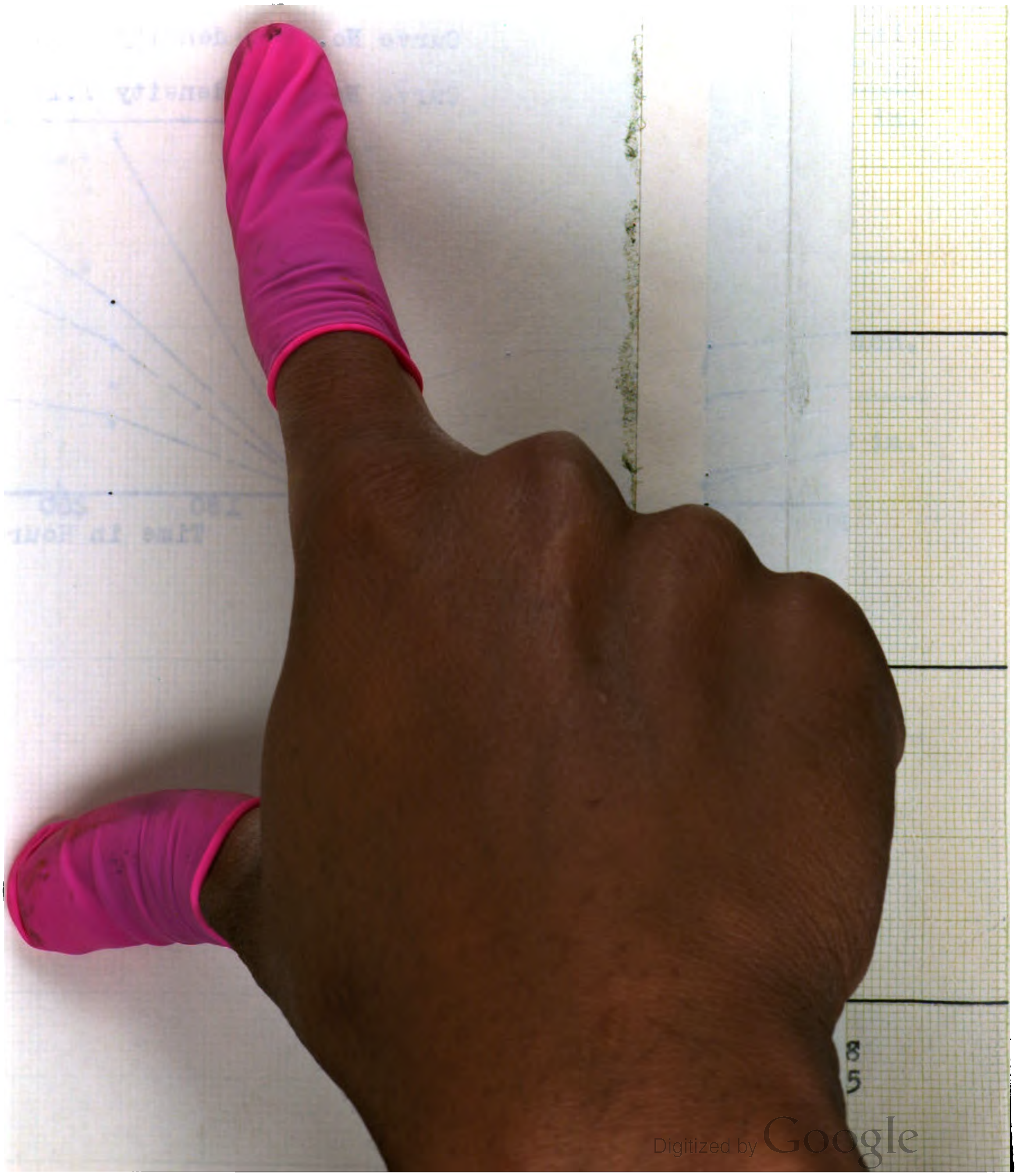
Cement Number N2
Average Temperature 66°F
Storage - Dry - Saturated.
Time in molds -21 hours.

Object of test:-
Constant $MgCl_2$ content
at a varying density.

	Batch Number.				
Composition:-	I	II	III	IV	V
Cement grs.	528	528	528	528	528
Sawdust grs.	312	312	312	312	312
Asbestos grs.	144	144	144	144	144
$MgCl_2$ c.c.	385	454	588	695	795
- density	1.31	1.28	1.23	1.20	1.18
Time inc.	Expansion test (increments)				
24 hrs.	.0349in.	not made	.0144in.	.0141in.	.0109in.
46	.0387		.0155	.0130	.0148
94	.0315	——	.0079	.0092	.0150
120	.0290		.0031	.0033	.0123
144	.0176		-.0039	-.0054	.0060
167	.0102		-.0100	-.0120	-.0010
Water added.	*				
192	.0430		.0228	.0181	.0098
216	.0807		.0404	.0297	.0135
264	.1148		.0606	.0402	.0276
Tensile str, in lbs. per square inch.	Tensile strengths (11 days)				
	93		330	326	370
Deflection	Cross bending tests.				
Box .02 in. ?	6 lbs.		20 lbs.	24 lbs. 36 ult.	32 lbs. 36 ult.
Air .02 ?	7lbs.		20 40 ult.	20 32 ult.	32 38 ult.
Mod. of Rup.	117		540	630	650
Mod. of Elas.	----	----	432,000	500,000	690,000
Loss in H_2SO_4	6%		7.7%	10.7%	13.1%
Gain in H_2O	5.5%		4.8%	5%	5.4%

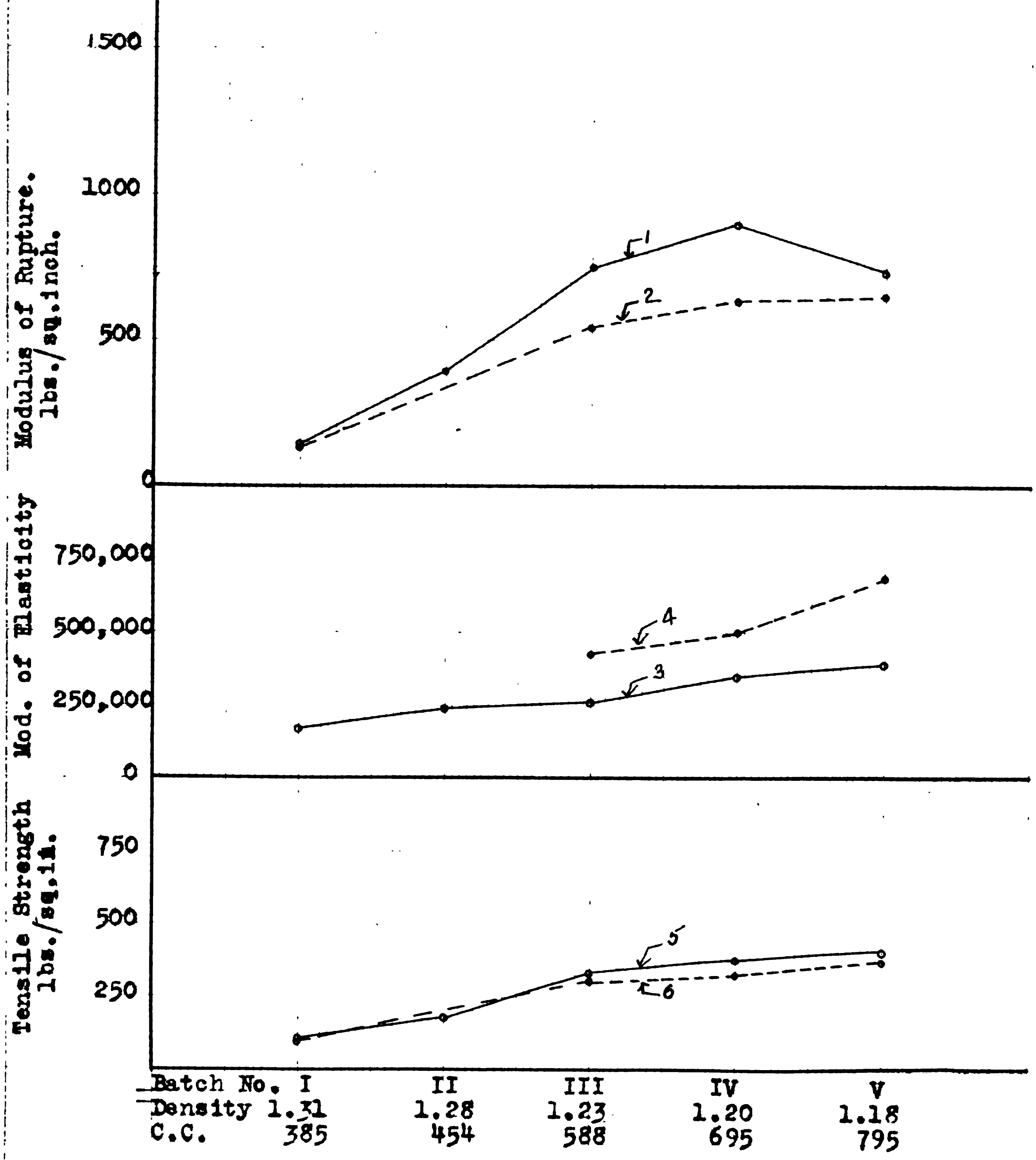
* Note:- On removing frame for adding of the water a sawdust grain was found under micrometer point of No. I.

No. N10



STRENGTH - CURVES

Curve No. 1 - Test No. N3 - Modulus of Rupture.
Curve No. 2 - Test No. N10 - " " "
Curve No. 3 - Test No. N3 - Modulus of Elasticity.
Curve No. 4 - Test No. N10 - " " "
Curve No. 5 - Test No. N3 -- Tensile Strength.
Curve No. 6 - Test No. N10 - " "



WEIGHT - CHANGE EXPANSION DATA.

TEST No. N9

Varying density of solution - constant liquid content. (836c.c.)

Batch No.	Density	W't lost. dry air.	Expansion	W't gain, sat. air.	Expansion.
I	1.27	1.17 %	.0293 in.	5.80 %	.0325 in.
II	1.23	3.21	.0166	3.46	.0188
III	1.20	7.60	.0111	2.53	.0096
IV	1.15	10.70	.0110	3.00	.0044
V	1.10	9.35	.0430	2.19	.0088

TEST No. N8

Varying amount of solution - constant density of MgCl solution.

Batch No.	Liquid, c.c.	W't lost dry air.	Expansion	W't gain sat, air.	Expansion,
I	580	4.5 %	.0079 in.	2.9 %	.0331 in.
II	721	7.8	.0106	2.9	.0204
III	835	9.2	.0254	2.9	.0110
IV	935	10.5	.0301	3.8	.0108
V	1080	11.3	.0306	5.0	.0108

TEST No. N 10

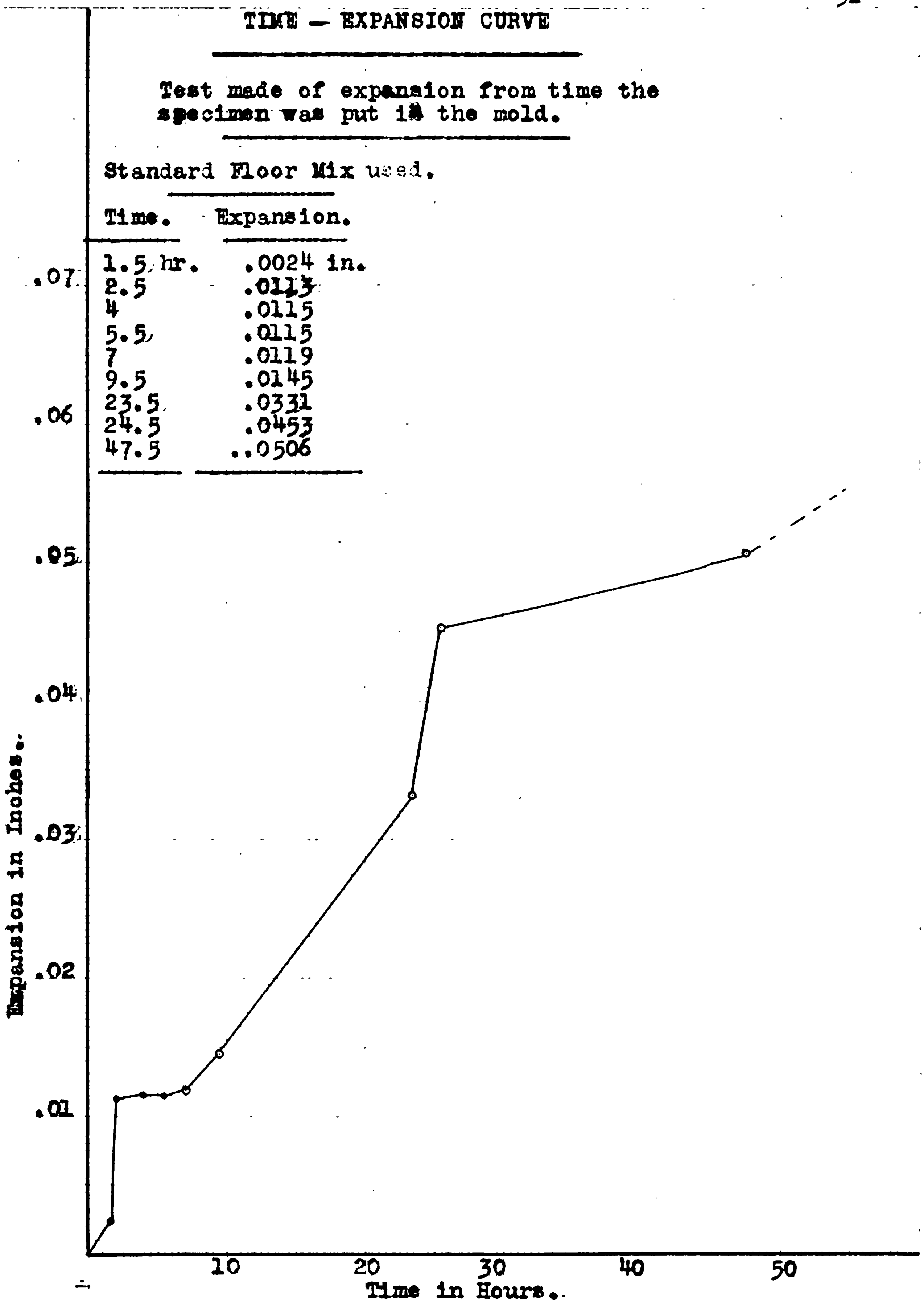
Batch No.		W't lost dry air.	Expansion	W't gain sat. air.	Expansion.
I	density 1.31 c.c. 385	6 %	.0102 in.	5.5 %	.1148 in.
III	density 1.23 c.c. 588	7.7 %	.0100	4.8	.0606
IV	density 1.20 c.c. 695	10.7 %	-.0120	5 %	.0402
V	density 1.18 c.c. 795	13.1 %	-.0010	5.4 %	.0276

TIME — EXPANSION CURVE

Test made of expansion from time the specimen was put in the mold.

Standard Floor Mix used.

Time.	Expansion.
1.5 hr.	.0024 in.
2.5	.0113
4	.0115
5.5	.0115
7	.0119
9.5	.0145
23.5	.0331
24.5	.0453
47.5	..0506



COEFFECIENT OF THERMAL EXPANSION DATA.

Test 1.

Test made on specimen of standard floor mix.

Length measured -13.75 in.

Micrometer readings:-
  1st reading 0.9150 at 3°C.
  2nd reading 0.8314 at 96°C.

Expansion - 0.0836 cm. = 0.03285 in.

Temperature range- 93°C. = 167°F.

$$\text{Coeffecient of thermal expansion} = \frac{0.03285}{13.75 \times 167} = 0.0000143$$

Test 2

Test made on specimen of standard floor mix.

Length measured - 13.75 in.

Micrometer readings:-
  1st reading 2.4601 at 17°C.
  2nd reading 2.4023 at 101°C.

Expansion 0.0578 cm. = 0.0228 in.

Temperature range -84°C. = 151°F.

$$\text{Coeffecient of thermal expansion} = \frac{0.0228}{13.75 \times 151} = 0.0000109$$

AVERAGE OF TWO TESTS = 0.0000126

RESULTS AND CONCLUSIONS.

Summary of Expansion Tests.

It has been though that the results of the tests and the conclusions to be drawn therefrom can best be discussed by a separate consideration of the different groups of tests. Accordingly the discussion has been separated into the divisions following.

1. Expansion tests on different cements. Open air and box storage. Test No. N1 - N2.

The object of making these tests was to determine whether any of the chemical constituents of the cement affected its change in volume in setting. The first test was made in the open air. While there was no pronounced volume variation noted in any of the cements that could be attributed to any of its chemical constituents, it was found that the expansions of all of the cements followed the humidity of the air. This is shown in the humidity curve of the air for the same period of time which is plotted on the same sheet.

The next test was made in the box to determine what volume variations would appear under constant storage conditions. The curves obtained from this test show that a uniform expansion curve can be obtained under constant storage conditions. The effect of varying atmospheric conditions is brought out more clearly by a comparison of the curve from a check specimen which was tested in the open air at the same time with the curves obtained in the box. This specimen showed a wide and uneven variation. There seems to be no relation, however, between the maximum expansion and the chemical constituents of the cement. For instance , of the two cements having the highest lime contents, one showed the larg-

est maximum expansion and the other the smallest.

2. Expansion tests on neat, 1 to 6 sand, and standard floor mixes. Test No. N5.

These curves show that the effects of the different atmospheric conditions on these mixes is similar, though their magnitude depend on the mix. The expansion in setting in the dry atmosphere appears to be a function of the amount of cement in the mix (MgO and $MgCl_2$). The expansion in a saturated atmosphere is also dependent on the amount of cement in the mix. It was thot before these tests were made , that the changes in volume of the mix might be due to change in the moisture content of the aggregate. But in this test it is seen that the mix containing no aggregate at all, i.e. the neat, showed the greatest expansion in both the dry and the saturated atmospheres. It would seem therefor, that the changes in volume are due to some action on the part of the cement by which it gives off or absorbs moisture, rather than to an expansion or shrinking of the aggregate.

3. Expansion test made with varying amounts of $MgCl_2$. Tests No. N6,N9,N7 and N8.

In these tests the amount of $MgCl_2$ used with a constant proportion of dry materials was varied in two ways:- (a) By varying the density of the solution, keeping its amount constant. (b) By varying the amount of the solution, keeping its density constant. Check tests were made with each method. In general it may be said that the change in volume in setting in a dry atmosphere is a function of the amount of $MgCl_2$ in the mix. This was the case in all of the runs. The constancy of volume, after the maximum expansion had been reached also depended on the amount of $MgCl_2$

in the mix, the specimen made up with a higher $MgCl_2$ content being the more stable.

It is even more difficult to draw a general conclusion regarding the effects of the $MgCl_2$ content on the volume changes in a saturated atmosphere. In one case (tests N7 and N8) the two tests checked; in the other (tests N6 and N9) the results obtained were exactly opposite in character. When the $MgCl_2$was changed by varying the amount of the solution at a constant density, the specimens having the more $MgCl_2$ were the more stable, i.e.,expanded the least. When the $MgCl_2$ content was varied by changing the density, with a constant liquid content the tests made in a saturated atmosphere did not check each other, and there seems to be no reason that can be given for this lack of uniformity.

4. Expansion tests made with a constant content of $MgCl_2$.

Tests No. N3 and N 10.

Two tests were made in which the content of $MgCl_2$ was kept constant, but the amount and density of the solution used was varied. In both these tests the widest change in volume occured in the specimens made up with the lowest amount of water in the solution,i,e., the highest density of solution. This held true for both the dry and the saturated atmospheric conditions.

5. Special expansion test.

From this test in which the change in volume was measured from the time the specimen was put in the mold, it would appear that the natural elasticity of the aggregate had an effect on the expansion during the first few hours, for a very large expansion was obtained in a rather short time. In order to draw definite conclusions on this point, a mix should be made and tested having an in-elastic filler substituted for the sawdust. Another

mix having an inert material in place of the cement might also be tested.

General Discussion of Expansion Tests.

It is difficult to draw any fixed conclusions regarding the expansion in a dry atmosphere for there are several variables which affect these expansions. One of these is the temperature while setting. It is seen in the tests run at a higher temperature that the maximum change in volume is reached more quickly and that there is a greater shrinkage of the specimens.. Another of these variables is the time that the specimens were left in the molds before being put in the expansion test frame. It is generaly true for the tests that where the greatest percentage maximum expansions were obtained, the specimens had been left the shortest time in the molds. For the longer the specimens are left in the molds, the firmer the cement can set, and hence the less will be the expansion due to the elasticity of the aggregate. That there is an expansion due to this elasticity was shown in the special expansion test which has been mentioned. Another factor which was not kept constant was the pressure with which the specimens were pressed into the molds, and this variation in molding pressure on account of the elasticity of the aggregate, would affect the expansion. This difference in pressure would not only affect different tests as a whole, but would affect the different batches of the same test. For it was impossible to mold the specimen from a very moist, semi-fluid mix with the same pressure as was required on a very dry mix.

The expansion tests made in a saturated atmosphere showed that the cement would expand almost without limit under these conditions. There was nothing in the tests, however, to show

whether this expansion was due to an absorption of water by the cement to form an oxychloride of a higher water content, or by an absorption of water by the uncombined $MgCl_2$ or MgO in the specimen, depending upon which was in excess.

The expansion tests as a whole showed the cement to be for the first three weeks at least, in an unstable state. In a dry atmosphere it tended to give off moisture and to shrink; in a saturated atmosphere it tended to absorb water and to expand almost indefinitely.

Discussion of Strength Tests.

These tests are shown graphically by curves in which the strengths are plotted against the variable of the cement, density or amount of solution, as the case may be.

The tensile strength curves show that a maximum tensile strength is obtained with a certain strength and amount of solution. This density was from 1.20 to 1.23, using 85 c.c. of solution per 100 grams of aggregate and cement. This was adapated as the standard, and was the density and amount that had been found by earlier workers in the Materials Testing Laboratory to give the best results.

The tensile strength curves of the test in which the $MgCl_2$ content was changed by varying the amount at a constant density of 1.20 have a well defined maximum, showing that either increasing or decreasing the amount of the solution from the standard lowers the tensile strength.

The tensile strength curves of the test in which the $MgCl_2$ content was changed by varying the density, keeping the amount of the solution constant do not show a maximum, but tend to become horizontal above a density of 1.23, showing that no propor-

tiomate gain in strength is obtained by increasing the density of the solution. On the other hand, a very great decrease in strength occured when the density of the solution was decreased. This would show that MgO could not be made into a cement using water only.

In the tests made with a constant content of $MgCl_2$ the specimens containing the most water were the strongest. This shows that a certain amount of water is necessary for the setting of the cement.

The modulus of rupture curves varied with the tensile strength curves so closely that a separate discussion of these is not necessary. The modulus of elasticity varied as the modulus of rupture. Its average value for all tests was about 500,000 lbs. / in^2.

Change in weight tests.

In these tests small specimens were made of the same mixes and were subjected to the same storage conditions as the expansion specimens and their weights were taken at the end of the different time periods. The loss in weight in the dry storage, (see WEIGHT-CHANGE EXPANSION DATA sheet) is dependent on the amount of moisture in the mix. Where the amount of the solution is kept constant it increases as the density decreases, that is, as the ratio of water to $MgCl_2$ in the solution increases.

On the other hand, the gain in moisture in a saturated atmosphere appears to be dependent on the amount of MgCl in the mix. In the test in which the $MgCl_2$ was kept constant the gain in weight was nearly constant for all of the mixes.

There seems to be no relation between the expansions and the moisture lost or gained.

This might be expected, for as has already been pointed out the expansion depends on several variables besides those of moisture or $MgCl_2$ content.

Coeffecient of Thermal Expansion.

The results of these tests seem comparatively high. This is probably due to the expansion of the sawdust on account of the absorption of oil from the hot oil bath, The oil absorption at the cold temperature was very much slower, hence it was possible to obtain constant readings at this temperature.

Approved:- Raymond J. Roark

June 13, 1916.

O. L. Kowalke

Assoc Prof Chem Eng.

June 13, 1916.

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